DEMONSTRATION of CORE NEUTRONIC CALCULATIONS FOR RESEARCH and TRAINING REACTORS via SCALE4.4

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ABSTRACT

In this work, full core modelling is performed to improve neutronic analyses capability for nuclear research reactors using SCALE4.4 system. KENOV.a module of SCALE4.4 system is utilized for full core neutronic analysis. The ORIGEN-S module is also coupled with the KENOV.a module to perform burnup dependent core analyses. Results of control rod worths for 1st cycle of Cekmece TR-2 research reactor are presented. In particular, coupling of KENOV.a and ORIGEN-S modules of SCALE4.4 is discussed. The preliminary results of 2-D burnup dependent neutronic calculations are also given.

INTRODUCTION

Monte Carlo technique is extensively used to perform in core neutronic and criticality calculations. There are several codes capable of doing such a calculation. Recently, there is increasing interest to perform burnup dependent core analysis. In some of these studies MCNP code is utilized. In this study, we introduce burnup dependent core neutronic calculations using Scale4.4 code system module KenoV.a and Origen-s module. In this paper, from now on the Scale4.4 code system, KenoV.a and Origen-s modules will be referred as Scale, Keno and Origen.

Scale code system Keno module is coupled with Origen module to perform burnup dependent core neutronic analysis of TR-2 research reactor. In order to do such a coupling, the input parameters for Origen module such as integrated group fluxes, fuel composition and power peaking factors of each assembly must be supplied by processing Keno output. The full core neutronic calculations are strongly dependent on control rod movements during the operation. Therefore, these movements are taken into account in the full core Monte Carlo simulation.

Our primary objective is to perform full core burnup dependent neutronic analyses using Keno and Origen. The structure of Origen code allows us to determine neutronic characteristics of each assembly utilizing the results of Keno module. To perform such calculations, the input data used in the Origen module must represent the cycle average integrated group fluxes and power peaking factors of each assembly.

The main problems related with burnup dependent analyses are; determination of burned fuel composition, which is strongly dependent on the location of the assemblies, and the representation of burned fuel composition to perform neutronic analyses on Keno module.

In the following sections, first the use of Keno and Origen for assembly level and full core neutronic calculations is discussed. Then, the preliminary results of Keno and Origen modules are compared with experimental data and 4-group diffusion calculations. Finally, the results of Origen-s are used to obtain burnup dependent fuel composition to perform EOC core power distribution, reactivity and control rod worths.

ASSEMBLY LEVEL MODELLING

The core of TR-2 (1st cycle) consists of 10 identical fuel assemblies, and 4 control rod assemblies. In this study, the modelling of fuel and control rod assemblies are performed by using Keno module.

The results of Keno module are used to determine Origen inputs to perform burnup analyses. However Origen outputs contain more than 200 fission products in LWR library which would be time consuming while running the Keno module. To optimize the number of isotopes in the fuel composition of assemblies, the Keno module was run with 4 different set of compositions. The results are presented in Fig I.

- I, Xe, Pm, and Sm only (4 fps*)
- Wims fission product library $\cap$ 44groupENDF5(Keno) library (39 fps)
- Origen library -isotopes >10^{-4} grams/assembly at EOC-(107 fps)
- Full Origen $\cap$ Keno library (186 fps)

* fission products

To decide which set of fission products to be used in burnup dependent full core calculations, the results given by Fig. 1 are compared. The comparison shows that the Wims fission product library would be the best choice.

FULL CORE MODELLING

The TR-2 full core consisting of 10 fuel assemblies, 4 control rod assemblies, 4 beryllium blocks and 2 aluminium blocks is modelled by using Keno. Even though these assemblies were designed as identical, there are variations in geometry and enrichment. The geometry of assemblies varies only with a couple of millimetres, which does not effect the neutronics of the core, but the variation in enrichment is taken into consideration for the neutronic calculations.

The BOC TR-2 core is modelled in Keno with each assembly of the same type having the same geometry but different compositions (Fig. 2). The Keno output is processed with an interface program K2O to determine integrated group fluxes and power peaking factor of each assembly. In Fig. 3 the parameters used in the Origen code for each assembly, ie, THERM, RES, FAST (see section for weight factors) and power peaking factors are given when all control rods are out.

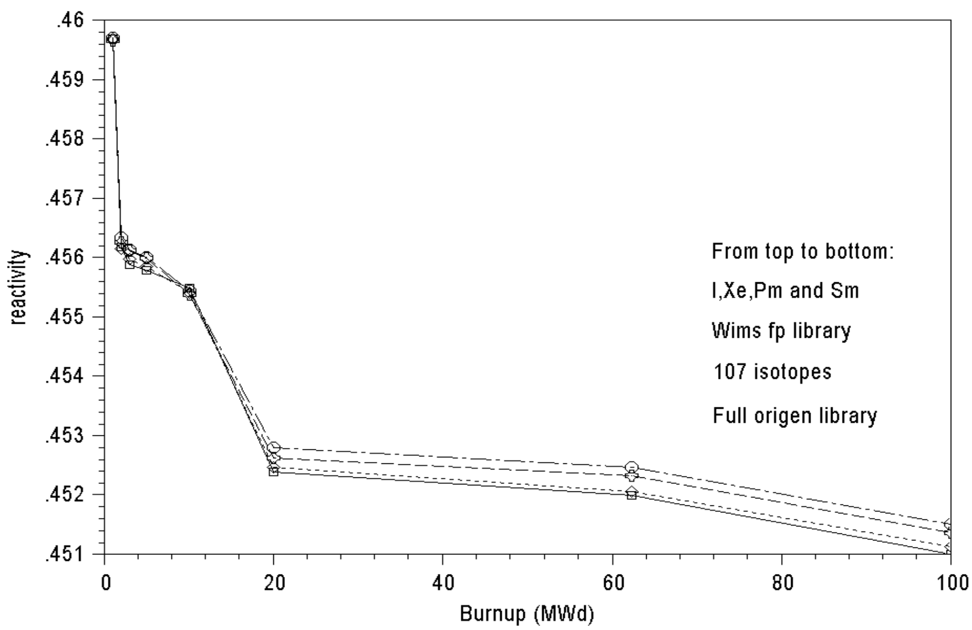
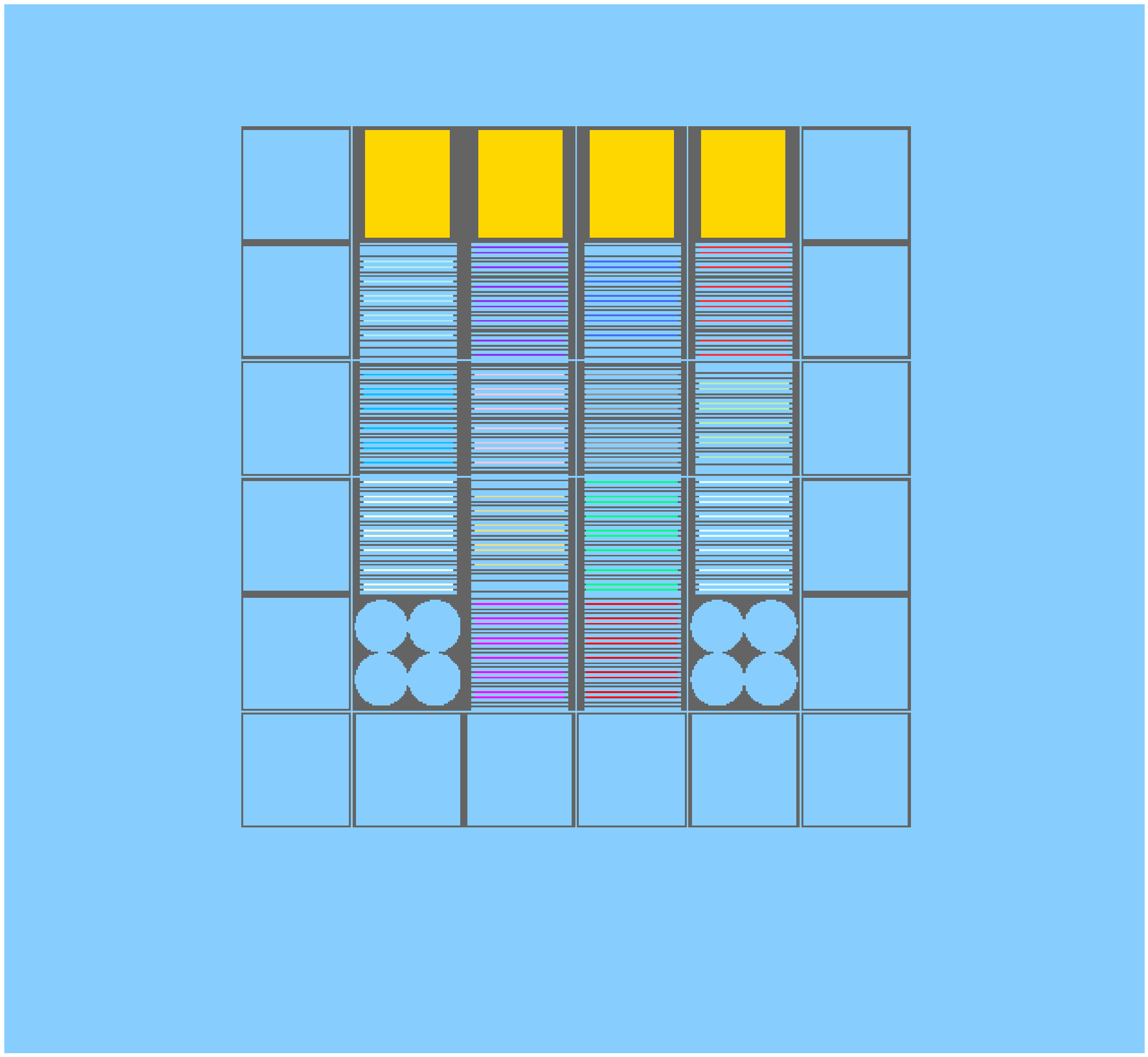


Fig. 2 Full core Keno output image



32 Be	42 Be	52 Be	62 Be
33 **PPF**: 0.970 **THERM**: 0.581 **RES**: 0.156 **FAST**: 2.244	43 OUT 0.890 0.572 0.172 2.380	53 1.125 0.566 0.187 2.535	63 OUT 0.757 0.584 0.149 2.142
34 OUT 0.845 0.580 0.156 2.283	44 1.275 0.563 0.191 2.690	54 1.254 0.562 0.194 2.722	64 1.056 0.579 0.167 2.434
35 1.008 0.584 0.155 2.294	45 1.116 0.561 0.196 2.763	55 OUT 0.910 0.570 0.179 2.527	65 0.978 0.580 0.158 2.343
36 Al	46 0.895 0.579 0.160 2.383	56 0.923 0.583 0.154 2.309	66 Al

Fig. 3 Parameters processed from Keno output at BOC, all rods out

After the determination of Origen input parameters, for each assembly, different Origen inputs are generated representing the fuel and control rod assemblies having different composition, integrated group fluxes and thermal power.

The excess reactivity at BOC has been determined by running Keno full core input. The control rods are then inserted one by one to obtain BOC rod worths(Table I). The axial variations of control rod worths are also obtained by changing the height of CRs at BOC (Fig. 4). The criticality is then achieved at the BOC by fully inserted CR at position no 43. Fig. 5 shows the results of neutronic parameters charecterizing each assembly.

Table I. Control Rod worths at BOC

Control Rod Worths BOC	Keno results (pcm)	Experimental Data (pcm)
CR stack no 43	5036	5575
CR stack no 34	4080	4423
CR stack no 63	2747	3265
CR stack no 55	6150	6304

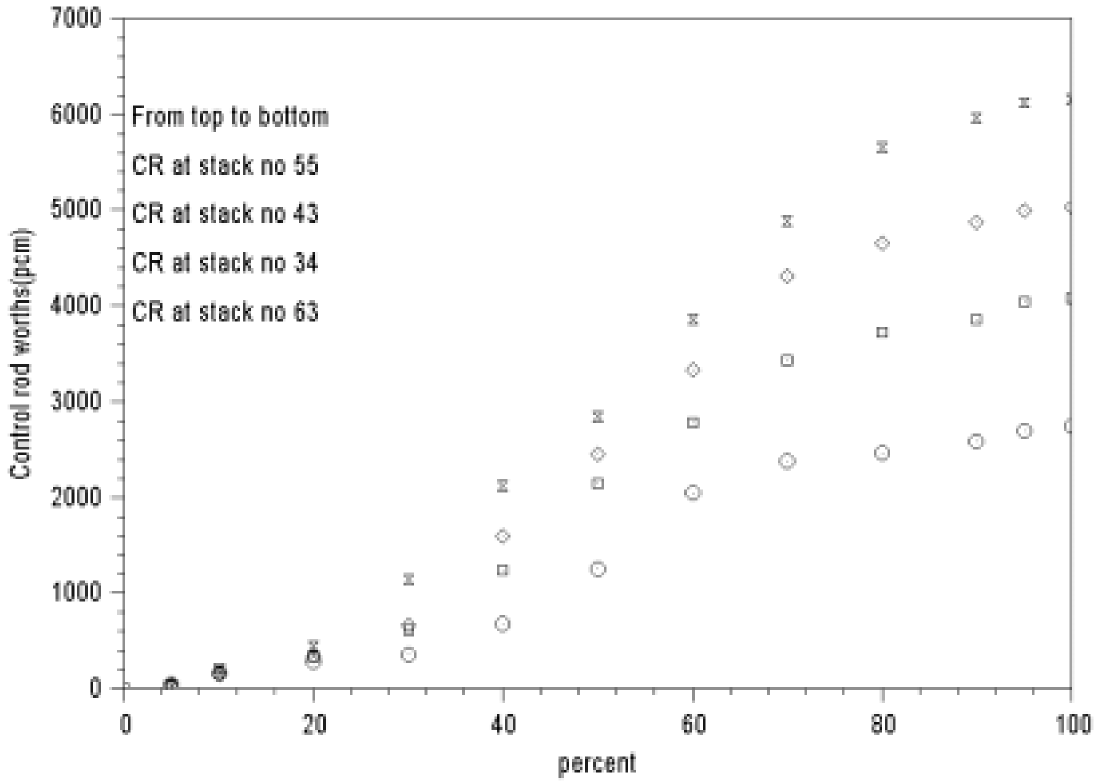


Fig. 4 Axial distribution of control rod worths at BOC

32 Be	42 Be	52 Be	62 Be
33 0.787 0.577 0.167 2.375	43 IN 0.489 0.543 0.247 3.118	53 0.993 0.561 0.200 2.712	63 OUT 0.766 0.583 0.153 2.222
34 OUT 0.811 0.579 0.161 2.377	44 1.104 0.554 0.215 2.981	54 1.294 0.560 0.198 2.797	64 1.159 0.578 0.168 2.491
35 1.088 0.583 0.157 2.377	45 1.222 0.561 0.199 2.853	55 OUT 1.013 0.569 0.183 2.613	65 1.136 0.580 0.162 2.432
36 Al	46 1.040 0.579 0.164 2.462	56 1.097 0.582 0.156 2.363	66 Al

Fig. 5 Parameters processed from Keno output at BOC, rod at stack 43 in

To obtain Xe equilibrium, Origen runs are performed with the parameters corresponding to critical configuration. Origen outputs are processed by the interface program O2K for Xe, I, Pm and Sm fission products to obtain Xe equilibrium. This continuous process resulted in Xe equilibrium approximately after 3 days with 54% of control rod in stack number 43 inserted. In figure 6, the results of neutronic parameters charecterizing each assembly are given for Xe equilibrium case.

32 Be	42 Be	52 Be	62 Be
33 0.879 0.582 0.163 2.336	43 54% in 0.678 0.557 0.208 2.745	53 1.065 0.560 0.199 2.696	63 OUT 0.767 0.581 0.155 2.239
34 OUT 0.823 0.578 0.163 2.403	44 1.181 0.554 0.209 2.925	54 1.273 0.558 0.199 2.808	64 1.117 0.578 0.168 2.491
35 1.088 0.583 0.157 2.377	45 1.222 0.560 0.199 2.853	55 OUT 1.013 0.569 0.183 2.613	65 1.136 0.580 0.162 2.432
36 Al	46 1.040 0.579 0.164 2.462	56 1.097 0.582 0.156 2.363	66 Al

Fig. 6 Critical configuration at Xe equilibrium, rod 43 54% in

To perform EOC core calculations, one of the technique employed in this study is based on the assumption that power peaking factors changes linearly during the cycle while control rod is withdrawn. The preliminary results are presented in figure 7. The k-eff values at BOC, Xe equilibrium and EOC are presented in Table II.

Table II. Comparison of k-effective values at BOC, Xe Equilibrium and EOC

k-eff values	Keno-Origen	Wims-E & Citation	Experimental Data
BOC	1.0619±0.0006	1.0622	1.0693
Xe Equilibrium	1.0316±0.0009	1.0308	Not available
EOC	1.0007±0.0006	1.0011	1.0076

32 Be	42 Be	52 Be	62 Be
33 0.975 0.586 0.156 2.240	43 OUT 0.904 0.572 0.174 2.380	53 1.130 0.567 0.186 2.536	63 OUT 0.759 0.584 0.150 2.150
34 OUT 0.844 0.581 0.158 2.303	44 1.269 0.562 0.191 2.676	54 1.252 0.564 0.191 2.689	64 1.059 0.574 0.168 2.451
35 1.006 0.582 0.155 2.311	45 1.108 0.561 0.196 2.763	55 OUT 0.901 0.570 0.179 2.518	65 0.983 0.581 0.159 2.371
36 Al	46 0.890 0.580 0.162 2.395	56 0.920 0.583 0.154 2.298	66 Al

Fig. 7 EOC parameters from Keno, all rods out

WEIGHT FACTORS FOR ORIGEN-S: THERM, RES, FAST

Origen requires data for all significant nuclide transition rates, by isotopic decay or neutron absorption. Isotopic decay rates are constant. While neutron reaction rates may vary with time, the Origen model requires that a constant or effective reaction rate be used during the period for which the library is applied. Origen uses the convention of normalizing cross sections to thermal flux and requiring thermal flux, or power to be input. The following may be used when neutron flux spectrum is available and with the assumption that thermal reaction rates follow that of a 1/v absorber.

$$THERM = 0.15906 \sum_{i=1}^{n} \frac{\phi_i}{\sqrt{E_i}} \Bigg/ \sum_{i=1}^{n} \phi_i$$

The groups 1 to n include the thermal groups (below 0.5 eV) and E_i is derived by some logical method for representing the energy of each group. THERM corresponds to the spectrum-averaged cross section in the thermal energy range.

RES is defined in the epithermal energy range (0.5 eV to 1 MeV) as follows:

$$RES = \frac{1}{\ln(E_2 / E_1)} \sum_{i=1}^{m} \phi_i / \phi_{th} = 0.06892 \sum_{i=1}^{m} \phi_i / \phi_{th}$$

Where the groups from 1 to m are the epithermal energy range and E_1 and E_2 are 0.5 eV and 1 MeV respectively.

FAST is defined as 1.45 times the ratio of the flux above 1 MeV to the thermal flux.

$$FAST = 1.45 \sum_{i=1}^{k} \phi_i / \phi_{th}$$

CONCLUSION

The full core burnup dependent neutronic calculations are performed using Keno and Origen modules of Scale. These results are compared with experimental data and 4-group diffusion results of CITATION code.

Our findings show that Keno and Origen modules can be used to describe burnup dependent neutronic characteristics of research reactors.

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